

# Optimization of Tig Welding Parameters for Hardness and Study the Effect on Microstructure of Titanium Alloy

**Mirza Muneer Baig**

*Assistant Professor*

*Department of Mechanical Engineering*

*Lords Institute of Engineering & Tech, Hyderabad*

**Asfan Mohiuddin**

*Assistant Professor*

*Department of Mechanical Engineering*

*Lords Institute of Engineering & Tech, Hyderabad*

**Mohd Akram**

*Student*

*Department of Mechanical Engineering*

*Lords Institute of Engineering & Tech, Hyderabad*

**Md Saif Khan**

*Student*

*Department of Mechanical Engineering*

*Lords Institute of Engineering & Tech, Hyderabad*

**Md Shadab Alam**

*Student*

*Department of Mechanical Engineering*

*Lords Institute of Engineering & Tech, Hyderabad*

## Abstract

Titanium alloys are used extensively in aerospace applications such as components in aero- engines and space shuttles, mainly due to their superior strength to weight ratio. The need to weld the alloy for certain engine components can expose the alloy locally to non-optimum thermal cycles and it is therefore of important to study the effect of process parameters on weld quality. To improve the welding quality of Titanium (Ti) plate an automated TIG welding system has been developed, by which welding speed can be control during welding process. Welding of Titanium has been performed in 9 phases with different set of parameters using L9 orthogonal array. Effect of welding current, welding speed and gas flow rate on hardness of welded portion has been investigated. Taguchi Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the welding characteristics of titanium, optimize the welding parameters and calculate contribution of each parameter. Optical microscopic analysis has been done on the weld zone to evaluate the effect of welding parameters on welding quality.

**Keywords-** Automated TIG Welding System, Orthogonal array, Signal to noise (S/N) ratio, ANOVA

## I. INTRODUCTION

Welding is a permanent joining process used to join different materials like metals, alloys or plastics, together at their contacting surfaces by application of heat and or pressure. During welding, the work-pieces to be joined are melted at the interface and after solidification a permanent joint can be achieved. Sometimes a filler material is added to form a weld pool of molten material which after solidification gives a strong bond between the materials. Weld ability of a material depends on different factors like the metallurgical changes that occur during welding, changes in hardness in weld zone due to rapid solidification, extent of oxidation due to reaction of materials with atmospheric oxygen and tendency of crack formation in the joint position. The Slag floats to the surface of weld pool and protects the weld from atmosphere as it solidifies.

## II. PROPERTIES AND ADVANTAGES OF TITANIUM (GRADE 5)

Ti-6Al-4V, Grade 5 alloy is the most widely used titanium grade. It is a two phase  $\alpha+\beta$  titanium alloy, with Aluminum as the alpha stabilizer and vanadium as the beta stabilizer. This high strength alloy can be used at cryogenic temperatures to about 800 °C. Ti-6Al-4V, Grade 5 alloy is used in the annealed condition and in the solution treated and aged condition. Some applications include: Compressor blades, discs, and rings for jet engines; air frame and space capsule components; pressure vessels; rocket engine cases; helicopter rotor hubs; fasteners; critical forgings requiring high strength-to-weight ratios.

This alloy is produced by primary melting using vacuum arc (VAR), electron beam (EB), or plasma arc hearth melting (PAM). Re-melting is achieved by one or two vacuum arc steps.

## A. Composition

Table 1: Composition of Titanium grade 5

	Al	V	Fe	C
% Present	5.87	4.3	0.12	0.03

## B. Properties

Table 2: Properties of titanium alloy

Density	4.42 gm/cm <sup>3</sup>
Melting point	1650 °C
Coefficient of expansion	9 µm/m °
Modulus of rigidity	40-44 GPa
Modulus of elasticity	105-120 Gpa

## C. Calibration of Speed

Before start of the experiment speed of the movable tractor was calibrated to get a required welding speed and found different speed value shown in table.

Table 3: welding speed value

Number on equipment	Speed value(mm/min)
1	50
2	100
3	150
4	200
5	250
6	300
7	350
8	400

# III. EXPERIMENTATION

## A. Process Parameters

The selection of parameters of interest was based on study some research papers and experiment preliminary. The identified process parameters are given below:

- 1) Welding current
- 2) Gas flow rate
- 3) Arc travel speed
- 4) Electrode size
- 5) Electrode extension
- 6) Electrode position
- 7) Welding position

The following process parameters are selected for the present work.

- a) Welding current
- b) Gas flow rate
- c) Arc travel speed
- d) Table Different parameters and their respective levels

Table 4: Different parameters and their respective levels

variables	unit	Level 1	Level 2	Level 3
Current (A)	amp	80	100	120
Welding speed(S)	Mm/min	200	300	400

Gas flow rate(G)	Liter/min	10	15	20
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### B. Experimental Procedure

Commercial titanium (grade 5) of thickness 5 mm was selected as a work piece material for the present experiment. Ti plate was cut with the help of wire EDM. After that, Surfaces are polished with emery paper to remove any kind of external material. After sample preparation, Ti plates are fixed in the working table with the flexible clamp side by side and welding done so that perfect weld beam is formed.

TIG welding with high frequency direct current (HF D.C) was used in experiments as it concentrates the heat in the welding zone. Throated tungsten electrode of diameter 2.4 mm was taken as electrode for this experiment. The end of electrode was prepared by reducing the tip diameter to  $\frac{1}{2}$  of the original diameter by grinding. This creates a sharp edge at the end of electrode. Before performing actual experiment the number trail experiments have been performed to get the appropriate parameter range where welding could be possible and no observable defects like undercutting and porosity occurred. Finally, experiment was done with the following set of parameters:

Table 5: Different experiments on TIG welding

Experiment no	Welding current	Welding speed	Gas flow rate
1	80	200	10
2	80	300	15
3	80	400	20
4	100	200	15
5	100	300	20
6	100	400	10
7	120	200	20
8	120	300	10
9	120	400	15



Fig. 1: Formation of weld bead on specimen for experiment 1



Fig. 2: Formation of weld bead on specimen for experiment 2



Fig. 3: Formation of weld bead on specimen for experiment 3



Fig. 4: Formation of weld bead on specimen for experiment 4



Fig. 5: Formation of weld bead on specimen for experiment 5

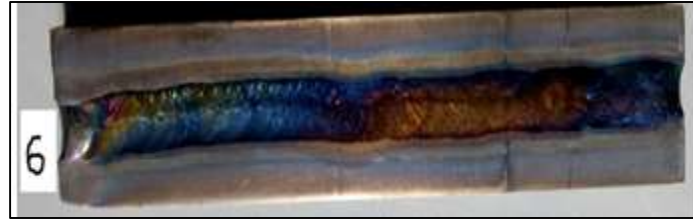


Fig. 6: Formation of weld bead on specimen for experiment 6



Fig. 7: Formation of weld bead on specimen for experiment 7



Fig. 8: Formation of weld bead on specimen for experiment 8



Fig. 9: Formation of weld bead on specimen for experiment 9

#### IV. RESULTS AND DISCUSSION

Hardness values for all the samples were measured and calculated average hardness as shown in table.

For calculating S/N ratio, "Larger the better" method is chosen.

Step 1: Select the design matrix and perform the experiments

Table 6: Response table for S/N ratio

Experiment no	Trail 1	Trail 2	Trail 3	Average	SN (db)
1	25	20	22.5	22.5	26.94
2	21.5	20.5	21.5	21.17	26.51
3	22.5	24	23.5	23.33	27.35
4	39	41	41	40.33	32.11
5	22.5	20	26.5	23	27.06

6	23	24	21.5	22.83	27.14
7	36.5	33	33	34.16	30.64
8	25	27	24.5	25.5	28.11
9	20	24.5	24.5	23	27.11

#### Step 2: Calculation of factor effects

The effect of a factor level is defined as the deviation it causes from the overall mean. Hence as a first step, calculate the overall mean value of n for the experimental region.

Table 7: average S/N ratio different factor levels

Factor	Level1	Level2	Level3
Current (amp)	26.93	28.77	28.62
Speed(mm/min)	29.89	27.17	27.2
Gas flow rate (l/min)	27.39	28.57	28.35

#### Step 3: Analysis of variance

Different factors affect the hardness to a different degree. The relative magnitude of the factor effects are listed in table. A better feel for the relative effect of the different factors is obtained by the decomposition of variance, which is commonly called as analysis of variance (ANOVA). This is obtained first by computing the sum of squares.

Table 8: ANOVA

Factor	Degree of freedom	Sum of squares	Mean square	Contribution
Current	2	6.28	3.14	26.96
Welding Speed	2	14.65	7.32	62.93
Gas flow Rate	2	2.35	1.18	10.09
Error	2			
Total	8	23.28		

The main purpose of analysis of variance is to investigate the influence of design parameters on hardness by including that which parameter is significantly affect the quality characteristics. By the use of ANOVA analysis the percentage contribution of welding speed is 62.93 %, welding current 26.98 % and gas flow rate is 10.09 %.

## V. MICRO STRUCTURE OF TITANIUM ALLOY FOR DIFFERENT WELDING PARAMETERS



Fig. 10: Optical microscopy image of the titanium alloy before welding



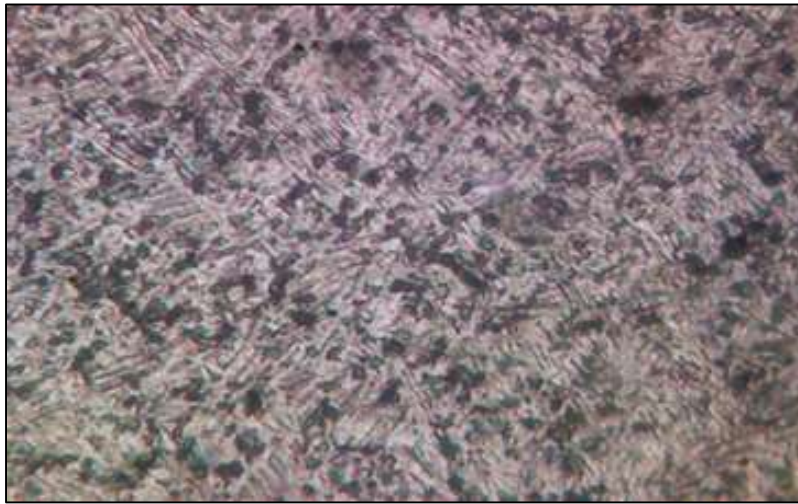


Fig. 11: Optical microscopy image of the weld bead for Experiment 1

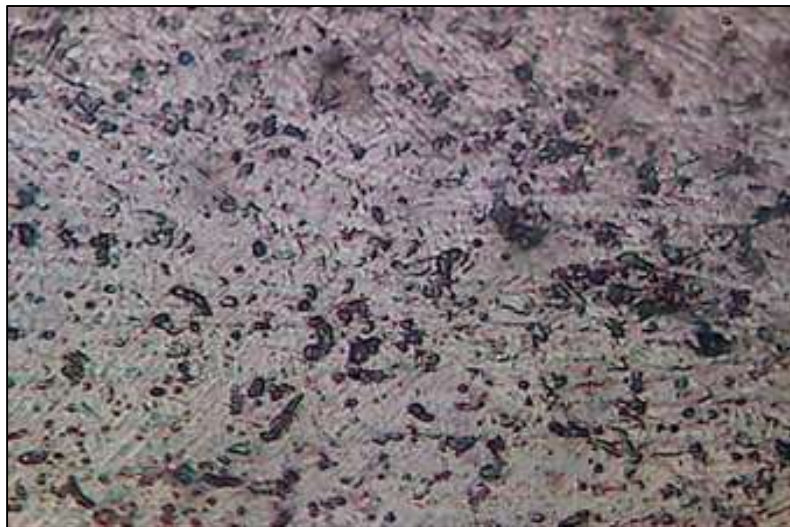


Fig. 12: Optical microscopy image of the weld bead for Experiment 6



Fig. 13: Optical microscopy image of the weld bead for Experiment 8

**A. Leica Optical Microscopic Images with Different Magnifications (200X and 500 X)**



Fig. 14: Optical microscopic image of the titanium alloy before welding (200X)

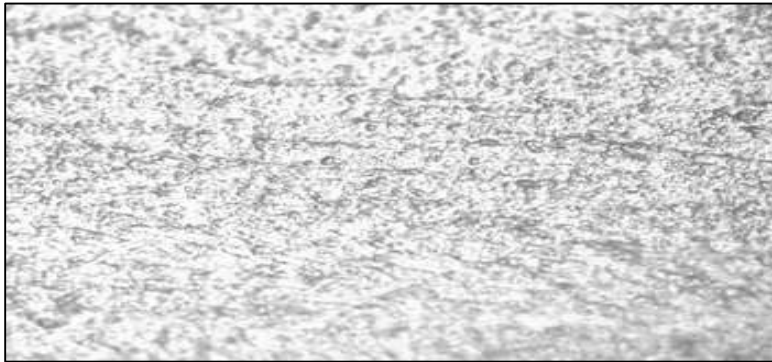


Fig. 15: Optical microscopic image of the titanium alloy before welding (500X)

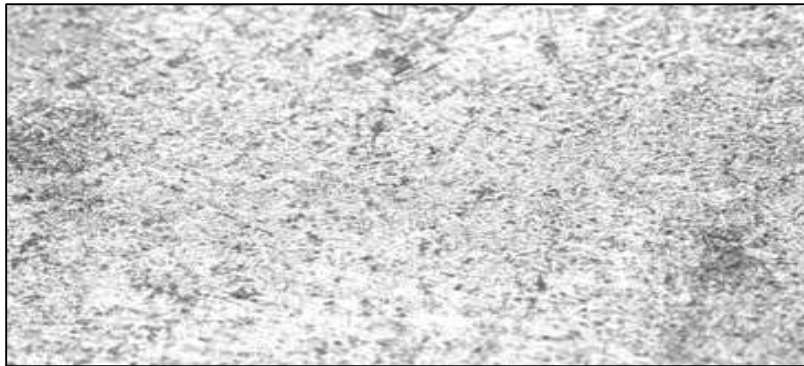


Fig. 16: Optical microscopic (Leica) image of the weld bead for Experiment 1 (current-80 amps, speed-200 mm/min, gas flow-10 lit/min) 200X

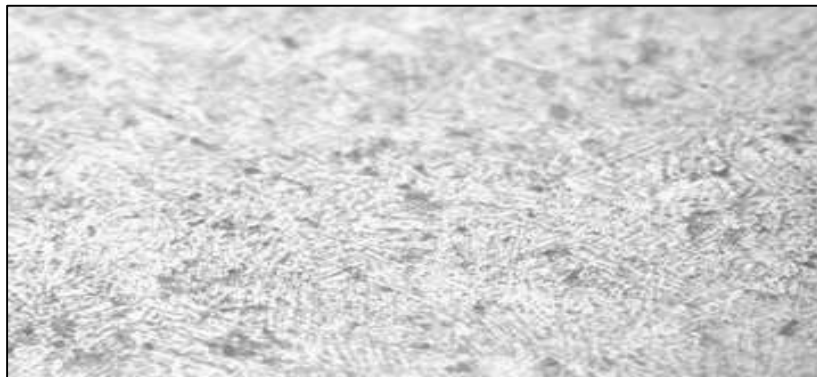


Fig. 17: Optical microscopic (Leica) image of the weld bead for Experiment 1 (current-80 amps, speed-200 mm/min, gas flow-10 lit/min) 500X

## VI. CONCLUSION

The purpose of the present experiment was to optimize the welding process parameters and find out their optimized values with the help of Hardness testing of the welding samples. The use of L9 (3×3) orthogonal array with three control parameters allowed this study to be conducted with a sample of 9 work pieces. From the experiment following conclusions can be made:

With the automated welding system uniform weld bead of Titanium plate can be possible.

- 1) With the automated welding system uniform weld bead of Titanium plate can be possible.
- 2) Welded zone hardness and welding strength or tensile strength of the weld joint depends on the welding parameters like welding speed and welding current and gas flow rate.
- 3) Taguchi design of experiment technique can be very efficiently used in the optimization of welding parameters in manufacturing operations.
- 4) As the welding current increases from 80 amps to 120 amps mean S/N ratio first increases and then decreases.
- 5) As gas flow rate increases from 10 ltr/min to 20 ltr/min mean S/N ratio increases first and then decreases.
- 6) Optimum parameters setting for hardness:

Table 9: Contribution of different parameters on hardness

Parameter	Levels	values	%Contribution
Current	Level2	100amp	26.96
Welding speed	Level1	200mm/min	62.93
Gas flow rate	Level2	50liter/min	10.09

It was found that welding speed has major influence (62.93% contribution) on hardness of weld bead for given range of welding current and gas flow rate. TIG welding while working normally gives optical microscope image indicates the presence of lamellar or bi-modular structure (precipitating very fine secondary  $\alpha$  in lamellar structures to give a so called bi-lamellar microstructure) leading to enhanced strength of the alloy.

## VII. FUTURE SCOPE

In present work weld bead formed without any filler material and without any temperature measuring instruments at welded zone. By measuring exact temperature at weld zone we can predict exact microstructure and properties of welded zone. Future work is to develop a new heat source model and simulate the TIG welding of titanium alloy sheets and plates.

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